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A MICROSTRIP LEAKY WAVE ANTENNA AND ITS PROPERTIES (PREPRINT)

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A Microstrip Leaky Wave Antenna and Its Properties

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ABSTRACT

It is well known that a microstrip transmission line can radiate if it is excited in its first higher order mode (with the fundamental or dominant mode suppressed). A new microstrip configuration is proposed that supports the first higher order mode while suppressing the fundamental mode. To quantify the leakage constants in the two cases for comparison purposes, several experimental means are considered to determine the source amplitude distribution from which the leakage constants may be deduced. First, an approximation to the source distribution is determined from the far field patterns themselves. Second, the source distribution is determined by carefully probing the near field. This paper uses these techniques to verify the performance of a new leaky wave antenna design.

Keywords: Leaky wave antennas, Menzel, conformal, microstrip, amplitude distribution.

1.0 Introduction

One of the "Holy Grails" for conformal antenna engineers is an antenna with wide bandwidth, high efficiency, a convenient radiation pattern, and low profile. These requirements typically are conflicting and an antenna engineer must make trade-offs amongst these requirements. There are a variety of conformal antennas used in practice, but perhaps the most studied of these is the microstrip patch antenna. Due to its relative simplicity of both modeling and construction, the patch antenna has been a subject of research and use for over thirty years. Munson [1] performed seminal work on this antenna as well as Carver and Mink [2]. The simple approximate models developed in these papers have been used frequently since that time and are now the topic of many antenna texts [3].

One of the major challenges associated with these antennas is the relatively narrow bandwidth [4]. Such antennas, if probe or microstrip fed, have a bandwidth typically less than 5% and often less than 2% [3]. Increasing the substrate thickness can increase the bandwidth; however, surface waves can be excited in such situations leading to a rather serious reduction in efficiency. This can be reduced by the introduction of shorting pins, or a cavity that has the effect of squelching surface waves. However, care must be used in doing so since placement of metal near the radiating edges of the antenna will have a significant impact on its properties. Since patch antennas are usually used in large arrays, due to their low cost and low gain, shorting pins or cavities cannot always be used due to the proximity of the antenna elements to each other. The result is strong surface wave coupling complicating the antenna synthesis task. Alternative feeding mechanisms can be used to increase the bandwidth, without exciting surface waves; however, the achievable bandwidth is typically on the order of 20-60% [5] and certainly a bandwidth of 2:1 or 10:1 are not achievable with patch antennas. Another approach to increasing the bandwidth, without a commensurate reduction in efficiency involves the use of magneto-dielectric materials [6]. However, the relatively high efficiency that can be achieved with such a design

requires low loss magnetic materials. Such materials are difficult to realize at high frequencies > 1 GHz.

There is a class of materials that are inherently wide bandwidth and have reasonable efficiency such as printed spirals (including slot spirals) and circular log-periodic as well as helix, bicone, and sleeve antennas. A general theory concerning frequency independent antenna design was presented by Rumsey [7]. The first two are amenable to conformal installation while the latter typically are protruding antennas. However, like the patch antenna, the radiation pattern for these antennas, depending on feed conditions or mode of operation chosen, has a peak normal to the platform in which it is installed. Examples of feed conditions that will result in a pattern peak away from this direction include higher-order mode excitation for the patch or a phase array of elements with the excitation feed phases chosen to steer the beam. However, it is a well-known fact that for a finite array of elements, there are scan limits on the beam for such elements.

An alternative, inherently wide bandwidth antenna belongs to the general class of traveling wave antennas such as the Beverage antenna and the rhombic antenna. These antennas utilize a load at the end of the antenna to dampen back reflections and hence have a limit on their efficiency; however, as the antenna becomes electrically longer, the main beam of the antenna squints towards the direction of propagation. An excellent overview of wide bandwidth apertures is given in [3]. The conformal version of a traveling wave antenna can be implemented using microstrip transmission line technology.

The fundamental mode for a microstrip transmission line does not radiate by intent. However, it is well known that a microstrip transmission line radiates if it is excited in its first higher order mode with the suppression of the fundamental or dominant mode [8]. Hence, it is theoretically feasible to realize a traveling wave antenna using microstrip transmission lines if properly developed. This aperture will in principle have wide bandwidth, an "end-fire" radiation pattern, high efficiency, and be ultra thin (much less than one quarter of a wavelength). It does have the drawback of a pattern peak that is frequency dependent; however, the impact of this property can be minimized for a range of frequencies given sufficient real estate [9]. A new configuration of this approach is proposed to exploit this microstrip technology for lightweight, low cost, facile fabrication of wideband apertures.

2.0 Leaky Wave Antenna Theory

A leaky wave antenna is a special form of traveling wave antenna characterized by a wave propagating interior to a guiding structure rather than exterior as in the case of a Beverage antenna. As seen in Figure 1, the dominant mode of a standard microstrip line does not radiate since the guided wave underneath the microstrip is coherent. However, when the dominant mode is suppressed, the first higher order mode undergoes a phase reversal of the electric field along a centered vertical axis, as shown in figure 2, and radiation of the first higher order mode occurs.

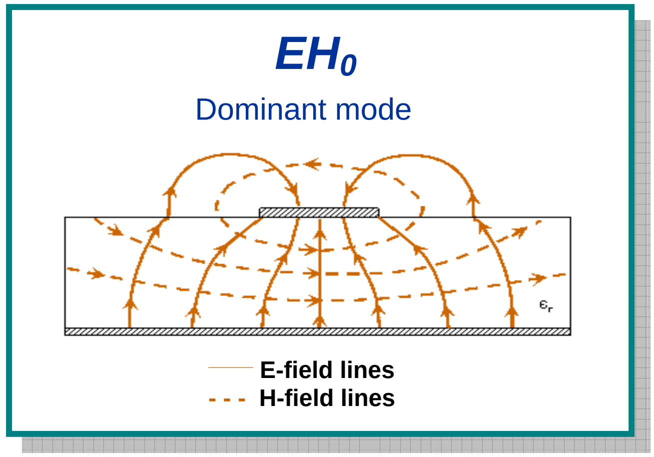

Figure 1: The electric field distribution of the dominant mode (does not radiate).

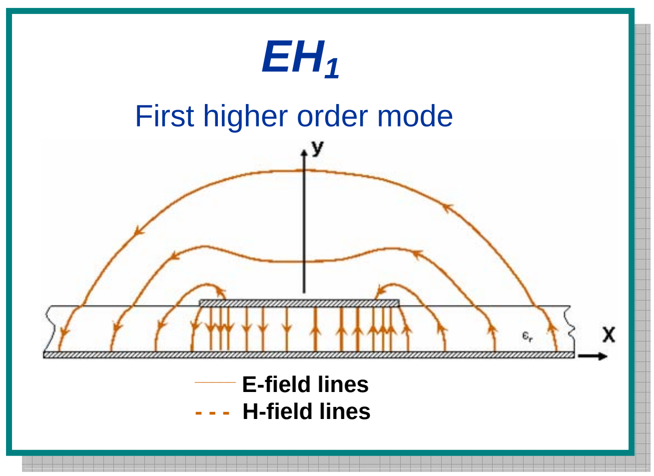

Figure 2: The electric field distribution of the EH_1 mode.

This guided-wave energy sets up a leaky wave exterior to the guiding structure and "leaks or sheds" power away from the guiding structure in a controlled way as the mode propagates from the feed to the termination. In doing so, radiation occurs with a peak that squints in the direction of propagation, as is the case with a Beverage antenna; however, this configuration is amenable to conformal installation. Menzel proposed an interesting

example of a leaky wave antenna [8]. His design, shown in Figure 3, is a wide microstrip line with several rectangular slots close to the feed end of the antenna along the centerline of the microstrip. These slots create a null electric field, or a virtual ground, at the center of the microstrip causing this mode to short to ground (see Figure 1 for the field distribution of this mode). Doing so allows the first higher order mode to propagate along the length of the microstrip since that mode already has an electric field null along the centerline (see Figure 2). Figure 4 illustrates Menzel's antenna design as fabricated in AFRL/SNRR's Radiation and Scattering Compact Antenna Laboratory (RASCAL).

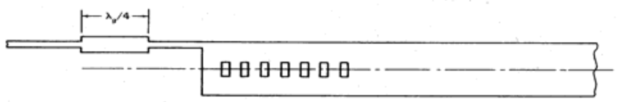

Figure 3: Menzel's Leaky Wave Antenna design.

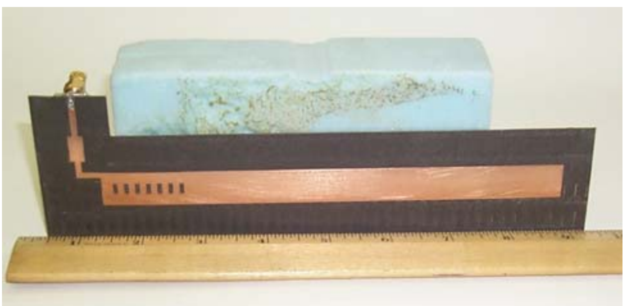

Figure 4: Menzel's Antenna fabricated and tested in RASCAL.

A new configuration of this type of leaky wave microstrip antenna design is proposed in Figure 5. To prevent the propagation of the fundamental mode, closely spaced metal posts may be placed longitudinally along the centerline of the microstrip. This physical null in the electric field suggests half of the antenna width can be discarded without impacting the suppression of the fundamental mode. This new configuration is shown in Figure 5. Since the footprint of the antenna is now smaller, an array of such elements can be packed closer together with less mutual coupling between elements. Figure 6 shows this new "half-width" design as fabricated and tested in RASCAL.

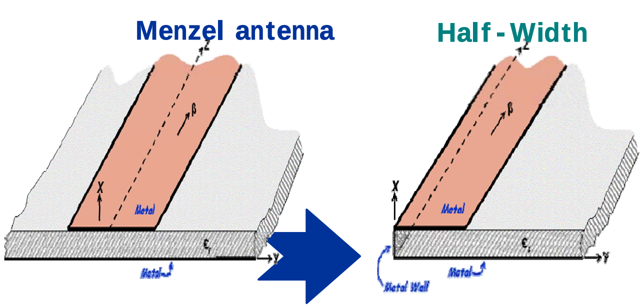

Figure 5: Menzel's design compared to the new "half-width" design.

Figure 6: New "half-width" design fabricated and tested in RASCAL.

3.0 Experimental Results

To illustrate the performance of this new configuration, several experiments were performed on both a standard Menzel antenna and the half-width antenna design, both fabricated in RASCAL's prototype lab. These microstrip antennas were created with a state of the art milling machine compatible with autoCAD, allowing drawings created in autoCAD to transmute to accurate tracings of designs etched into or out of copper substrate to the accuracy of a tenth of a millimeter. Both antenna designs were fabricated on Rogers 5870 duroid substrate made of PTFE glass fiber with a dielectric constant of ε_r = 2.33 and a thickness of .787 mm. The length of each antenna is 190 mm beginning where the width opens up to maximum width and ending at the antenna terminus. The Menzel design width is 15 mm while the width of the half-width aperture is, obviously, 7.5 mm. Figure 7 shows pattern measurements made in the RASCAL compact range. These results indicate that the configuration in Figure 6 produces a similar radiation pattern as the Menzel design (see Figure 4) with the reduced aperture footprint. Figure 7 illustrates a comparison of the measured far-field patterns at 6.7 GHz.

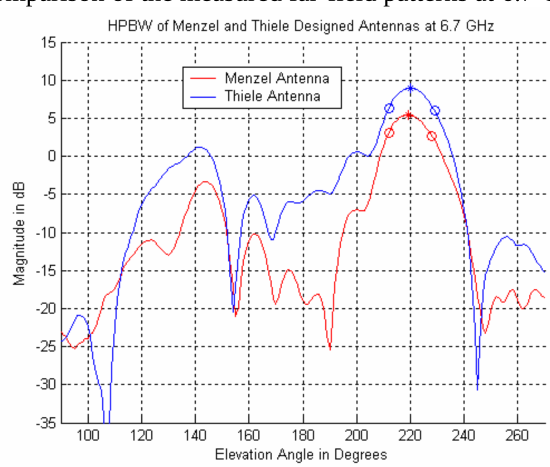

Figure 7: Menzel and "half-width" antenna patterns at 6.7 GHz

For leaky wave antennas, it is desirable to compare the leakage constant, α, and the propagation constant, β. The

leakage constant impacts the pattern beam width and is critical for minimizing the length of the antenna. The propagation constant determines the angular location of the pattern peak. From Figure 7 it is observed that the half-power beam width (HPBW) beam widths are 16^o for Menzel's configuration and 17^o for the half-width configuration. This indicates that the leakage constant, α, is approximately the same in each case. As seen in Figure 7, the pattern peak is almost at the same angle for the two cases; this suggests that the propagation constant, β, is approximately identical for the two cases.

Since the far-field is but a coarse indicator of the actual source distribution, it is desirable to compare the actual α and β for the two antennas. To accomplish this, measurements of the source distribution were taken by probing the fields near the antenna in RASCAL's near-field anechoic chamber (Broadband Antenna Near-field Test & Measurement, or BANTAM) adapted for that purpose. Two different probe configurations were used. One was a resonant dipole (Figure 8) and the other a monopole probe (Figure 9). Both were useful for determining β, but the results using the dipole were sensitive to its height above the antenna making the determination of α difficult. If the dipole is too close to the antenna, the dipole perturbs the field in an unacceptable manner while the evanescent propagating mode requires the probe to be near the antenna. In each probe case, measurements were taken at increments of one wavelength from one to four wavelengths in total distance. The monopole probe was most effective in obtaining accurate amplitude distribution results at a distance of > 1 wavelength from the antenna under test.

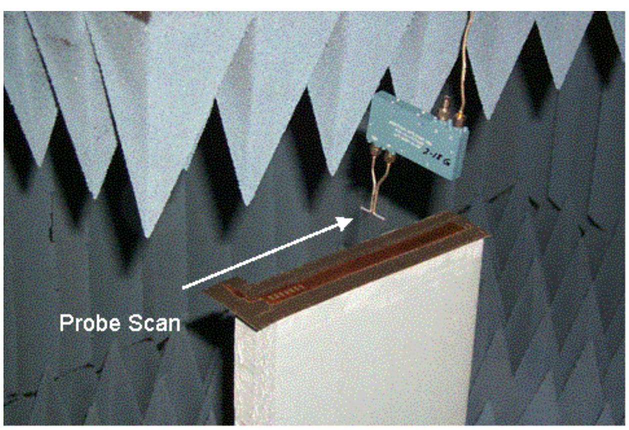

Figure 8: Dipole probe setup for near-field measurement in BANTAM.

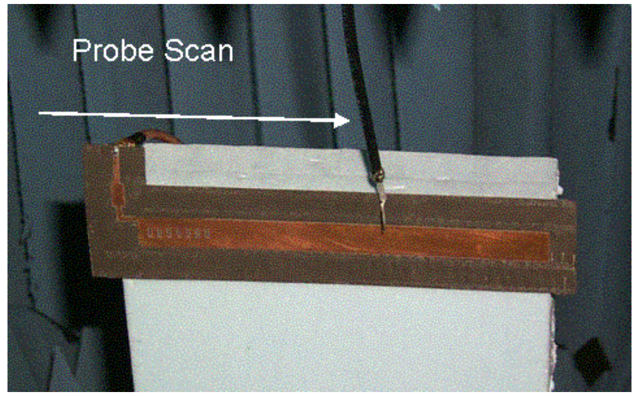

Figure 9: Monopole probe setup for near-field measurement in BANTAM.

Results obtained with the two probes are shown in Figs. 10 & 11 for the dipole and monopole probes, respectively. As is evident, the electric fields are largest above the antenna itself with attenuation along the propagating axis; however, the fields do not decay to zero. Indeed, the field at the antenna termination is only 20 dB below the peak and there is a non-zero field off the antenna as expected with such a simple design. Since the field is not fully decayed at the termination, a small standing wave is established (note the ripples in the near-zone field) and this consequently causes gain fluctuations as a function of frequency. Note further that the near-zone fields are very similar to those of the Menzel design.

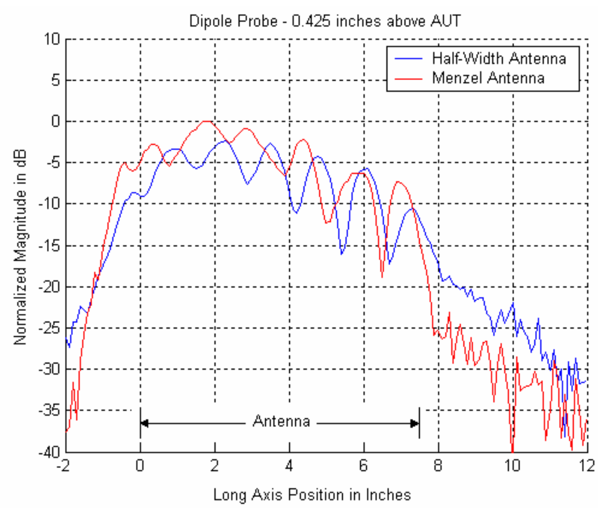

Figure 10: Dipole probe excitation .425" above AUT.

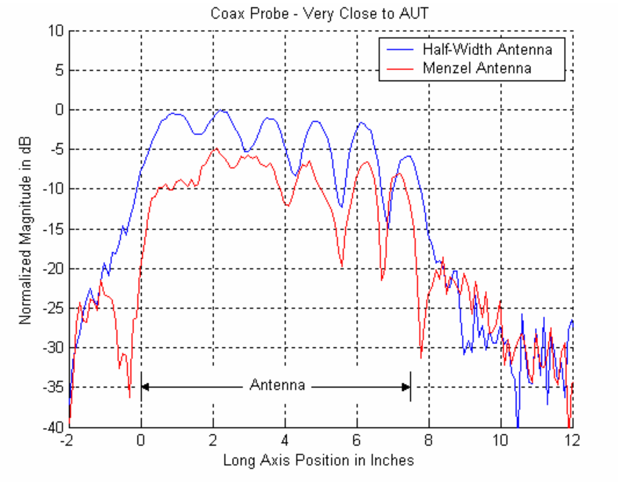

Figure 11: Coax monopole probe excitation directly next to AUT.

4.0 Conclusions

A novel aperture, based upon the concepts first articulated by Menzel [8] has been designed, fabricated, and tested. It is ultra-thin, has wide bandwidth potential, and has a convenient radiation pattern. The length (for low frequency limit) and the onset of the next higher propagating mode (for the high frequency limit) ultimately limit the bandwidth. It is shown that the new configuration has half the lateral size as the Menzel antenna while having nearly identical radiation patterns. Preliminary near-field probe measurements indicate that the two configurations produce similar amplitude distributions with the ripple primarily due to the length of the element. Further data to confirm these presuppositions will be presented at the symposium.

With its compact size, it is expected that this new configuration is more amenable to arraying in the least possible footprint.

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